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TECHNICAL REPORT BRL-TR-3111

**BRL****SURVIVABLE TIRE SYSTEM (STS) TEST STRATEGY:  
TECHNICAL PHASE****DTIC**  
**ELECTE**  
**JUL 25 1990**  
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**U.S. ARMY LABORATORY COMMAND****BALLISTIC RESEARCH LABORATORY**  
**ABERDEEN PROVING GROUND, MARYLAND**

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 1990		3. REPORT TYPE AND DATES COVERED Final, Apr 89 - Apr 90
4. TITLE AND SUBTITLE SURVIVABLE TIRE SYSTEM (STS) TEST STRATEGY: TECHNICAL PHASE			5. FUNDING NUMBERS  PR: 1L162618AH80	
6. AUTHOR(S) Barry A. Bodt, James E. Schall, and Sherman A. Snapp				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Ballistic Research Laboratory ATTN: SLCBR-DD-T Aberdeen Proving Ground, MD 21005-5066			10. SPONSORING/MONITORING AGENCY REPORT NUMBER  BRL-TR-3111	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The U.S. Army Tank Automotive Command tasked the U.S. Army Ballistic Research Laboratory to conduct the technical testing phase of a research program intended to enhance the survivability of combat vehicle tire systems. The study results will determine the research direction of the program, which if successful, will culminate in the fielding of new tire systems on all Army vehicles, allowing future soldiers to engage the enemy, sustain tire damage, and remain sufficiently mobile to return to their unit. Initially, the program involves only the High Mobility Multi-Purpose Wheeled Vehicle. This document focuses on the resolution of testing considerations such as the development of a device allowing damage to tires which are in motion and under load, a practical means of simulating representative fragment damage, and the use of statistical experiment design to answer a wide range of questions. This document defines the testing sequence and subsequent analyses to be performed. <i>Keywords</i>				
14. SUBJECT TERMS High Mobility Multi-Purpose Wheeled Vehicle, Survivable Tire Systems, Experimental Design, Fragment Simulation, NATO-Finabel Standard, factorial design. (SLDW)			15. NUMBER OF PAGES 66	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

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## ACKNOWLEDGMENTS

The authors gratefully acknowledge Mr. Tom Martindale and Mr. Rick Kane for their contributions to the proofing of the BRL test stand in preliminary testing, Dr. Ken Unruh for his guidance in the effort to achieve representative fragment damage, Mrs. Annette Wiseman for preparation of the document, and Mr. James Matts and Mr. Bill Baker for their reviews of this report.

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## 1. INTRODUCTION

### 1.1 Program History

An effort is underway to enhance the battlefield survivability of combat vehicle tire systems. The impetus for current investigations dates back to a 1979 issue paper, submitted to DA by the US Training and Doctrine Command (TRADOC). In 1985 the Tank Automotive Command (TACOM) established a tire task force, the need for which was supported by the results of a 1984 independent evaluation of one tire system performed by the Operational Test and Evaluation Agency (OTEA). OTEA observed that when the run-flat tires for the High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) were run flat for 30 miles, the tires became unserviceable and had to be replaced. The objective of the TACOM Tire Task Force is to identify a survivable tire system (STS) technological replacement which demonstrates acceptable battlefield survivability. A two-phase approach (operational and technical) has been adopted to screen available STS technologies in search of candidates for more intense research and development. The operational phase, considering the standard and new STS technologies, was completed by the Combat Developments Experimentation Center (CDEC) in 1987. The technical phase, the focus of this paper, is being conducted under the supervision of the Vulnerability Lethality Division (VLD) of the Ballistic Research Laboratory (BRL) according to the test plan developed by the Probability and Statistics Branch (PSB) of the Systems Engineering and Concepts Analysis Division (SECAD) of the BRL.

It is necessary to briefly review the operational phase so that the purposes of the technical phase are clearer. In the CDEC exercise, the operational performances of eight candidate HMMWV tire systems were examined. The test procedure began by damaging the right front tire by shooting into it seven 7.62mm rounds in accordance with the NATO/FINABEL standard, dated 5 January 1984. The vehicle was then driven on a test course consisting of three terrains: cross country, secondary road, and primary road. The terrain classifications were made by engineers from Waterways Experiment Station (WES). The vehicles traveled a maximum of 102 miles or less if the tire became unserviceable before completing the course. The principal quantitative measure was the speed of the vehicle over each course segment and the number of miles until failure for each tire--102 miles if the tire remained serviceable. In addition, subjective information regarding ride-performance measures was gathered via questionnaires filled out by the drivers and data collectors. Auxiliary data were collected and analyzed by WES, focusing on the stress to the vehicle and comfort afforded by each tire system, as assessed by measuring the power absorbed by the front axle and by the driver's seat in accordance with TACOM procedure. Some contributions of the CDEC and WES analyses were to rank the STS technologies, to suggest modifications for new STS technologies, to raise concerns over power absorbency, and to demonstrate that many STS technologies fail after degradation before traveling 102 miles.

To complete information supporting STS selections for further study, TACOM has contracted the BRL to augment the operational test information by examining, in detail, factors which influence the failure of these systems. The perceived need for further testing stems from questions raised during the operational phase. For example, an important thrust is to quantify and compare the influence on tire system performance of shrapnel-induced damage with that of 7.62mm rounds. Also to be studied are the influences of tire pressure (high or low), tire motion (moving or standing), tire position (front or rear), and impact angle of obliquity. Finally, BRL is to compare the STS technologies subject to these varying test conditions.

## **1.2 Technical Test Phase Objective**

The objective of this effort is to provide technical performance information for use in tire selection from among the STS technologies. The information must complement the operational phase exercise, so as to be considered an extension to it and not a completely different evaluative process. The test must provide a means of repetitiously propelling a representative size shrapnel (fragment) simulator at STS prototypes to impact at representative velocities. Representative is considered to define the size and velocity of the shrapnel that would impact the tires from ranges at which the vehicle could be expected to be operational or readily repairable by Battlefield Damage Assessment and Repair (BDAR) teams. The test must assess the influence of the possible degradation factors including those introduced in Section 1.1.

## **1.3 Purposes and Organization of this Document**

The purposes of this document are to explain and justify the experimental strategy which was proposed by the BRL and approved by TACOM and the Tire Task Force Executive Committee, and to introduce the new BRL test stand which was developed to meet the fragment damage study requirements.

The remainder of the report is partitioned as follows. Section 2 outlines the necessary requirements for the successful STS technology. Section 3 describes the adopted test strategy and Section 4 presents the methods for collecting and analyzing the data according to the strategy of Section 3. Section 5 addresses two special concerns: the simulation of fragments and the method by which tires can be safely and consistently damaged when in motion. Section 6 provides an overview and critique of the proposed test.

# **2. PERFORMANCE REQUIREMENTS FOR HMMWV TIRES**

## **2.1 Background**

The proposed STS prototypes approach the challenge of overcoming or resisting battlefield degradation in basically four different manners. When combat tires are

exposed to small caliber munitions and shell fragments, they will surely tear, puncture, or in some other way be damaged so as to induce partial or complete deflation. In order for military objectives to be satisfied, the survivable tire system will either successfully negate this damage or be structurally capable of supporting vehicle mobility without benefit of full tire pressure. Taking the first tack, the sealant tire systems contain chemical compounds which are intended to flow to a source of air loss, solidify, and thereby negate the threat damage. Run-flats take the second tack and are able to support the vehicle with a metal or plastic insert which acts in the tire's stead when the tire is deflated. Self-supporting tires are so named because molded into the tread is a rigid fiber glass band, designed to carry the tire's full load in the absence of tire pressure. Solid urethane tires circumvent the problem by containing no air to be lost, but they do so at the cost of additional weight, inhibiting vehicle mobility (Drelling et al., 1987).

The military objective is that HMMWV tires remain serviceable when degraded through battlefield exposure to small caliber munitions and shell fragments. Serviceable means that the tire exhibits performance consistent with the standards specified in the NATO/FINABEL standard, dated 5 January 1984. Summarized expectations set forth therein say that the combat tire must possess (as nearly as possible) the same over-the-road performance as the classic radial tire, in terms of maximum vehicle speed and lateral and longitudinal traction and stability. After degradation, normal military performance of the vehicle is still required when no more than two tires (one drive and one steering) are damaged. The selection criteria must be driven by the military objectives summarized above. The pertinent portions, providing more detail, have been extracted from the standard and are addressed below. After each requirement, a comment is made as to how the requirement is addressed in the proposed test strategy for the technical phase.

## 2.2 NATO/FINABEL Standard

### 2.2.1 Characteristics Before Perforation (Inflated)

The combat tire must possess (as nearly as possible) the same over-the-road performance as a classic radial tire including: maximum vehicle speed, lateral traction and stability, and longitudinal traction and stability. (Comment: Objective\* and subjective.\*\*)

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\*Statistical assessment based on strictly quantitative data.

\*\*Assessment based on questionnaire responses.

The combat tire must provide the same contact off-highway and cross-country mobility as a classic radial tire. (Comment: Subjective.)

In normal service the combat tire should be as repairable and remountable at the battalion level as the classic radial tire. No special combat tire tools should be required. (Comment: Subjective.)

### 2.2.2 Performance After Perforation

A "perforation" is the designation of any damage caused by automatic weapon fire (ball ammunition), artillery bursts (shrapnel), anti-personnel mines (shrapnel, shot, or flechettes), tree trunks (splinters, stubs, or stakes), and other combat area debris such as shell casings, ration can tops, and broken glass, which the tire might receive in combat. After perforation, the tire must maintain the minimum performance levels listed herein. (Comment: Shrapnel and automatic weapon fire only.)

Normal military vehicle performance is required when no more than two tires, one powered and one steering, are perforated. It is desirable that normal military vehicle performance be maintained after 50% of the tires have been perforated, simulating systematic fire perforating all tires on one side (Korea), as well as random perforations from anti-personnel mine overruns (Viet Nam). (Comment: Objective.)

The military vehicle with one steering/driving tire or two (one driving and one steering) tires deflated is required to pass the hard-surface road test and cross-country terrain test. For the hard-surface road test, the system must complete 50 km (30 miles) of a 75 km (45 mile) route without the perforated tires demounting or auto-igniting. This must be accomplished without significantly affecting speed, stability, maneuverability or steering under the following conditions over a paved course which features sections of straight level, hilly and curved (75 to 300 feet radii) roadway. For the cross-country terrain test, the system must complete two hours of operation at an average speed of 20 km/hr (12 mph) over a "rough" winding course featuring a limited number of steps (embankments), ditches, tree trunks, grades and side slopes over geologically natural terrain including sand, clay, aggregated stone, and loose rock without immobilizing the vehicle for any cause which would not have occurred if all tires had been inflated. (Comment: All terrains are incorporated in the 30 mile test course in accordance with the mission profile percentages for reliability testing.)

**TABLE 2.1**  
**TABLE 2.1. MISSION PROFILE**  
 Assumes 30 Mile Course Segment

<u>COURSE</u>	<u>MILEAGE</u>
Primary Roads 30%	9 miles
Secondary Roads 30 %	9 miles
Cross Country 40%	12 miles

### 2.2.3 Perforating the Tires

At a distance of 50 meters, fire five 7.62 mm rounds into the side wall and two 7.62m rounds into the tread. The tires may be perforated before mounting on the test wheel positions in order to eliminate potential vehicle damage. (Comment: All mounted.)

The perforated tires will be mounted on the heaviest loaded driving wheel on the walking beam position and the opposite side steering wheel. If the heaviest load is carried by a steering wheel tire, the test may be completed with one tire. If the vehicle's tires are independently suspended, two tests are required; one steering tire and one driving tire carrying the heaviest load. (Comment: Adhered to requirement.)

## 3. EXPERIMENTAL STRATEGY

### 3.1 Failure Definition

It is important to be able to determine when the tire system has failed. Consistent with the CDEC exercise, the tire system can fail in two ways, the first being a subjective judgement. After degrading the front-right tire with 7.62mm rounds, the vehicle was taken out on the test course. At regular intervals, or when handling concerns arose, the tire was inspected for damage. If for any reason the tire was judged to be unserviceable, the tire system was considered to have failed and the test of that tire was stopped. In the CDEC report, common notations describing the condition of the failed tire include "side wall came apart destroyed... run-flat device disintegrated ... tire came off rim ... bead lock broke."

The second way in which a tire system can fail is according to the 50%-Rule. The 50%-Rule says that the tire system is considered to have failed if the driver, in order to maintain vehicle control, has to reduce his speed by 50% or more relative to the normal operating speeds for each of the three terrains. The need for this rule stems from the possibility that a tire does not look bad enough to be judged to have failed, but performs so poorly that NATO/FINABEL requirements are not met. A consideration when applying this rule is that varying driver strengths may influence the degree to which the driver must slow to maintain control. To account for this, normal driving speeds will be determined for each driver. This will be accomplished with a preliminary base-line test, discussed in detail in Section 4.1.

### **3.2 Experimental Response and Influencing Factors**

In this section, all of the variables considered in this study are defined. They are classified as to response, test factor, or control factor. Within each category, the factor and its levels are defined, and the rationale for its inclusion in the study is given.

#### **3.2.1 Response**

By response, we mean the principal measure of performance to be used in the assessment of tire performance. The response for the study is the number of miles traveled after degradation before system failure, where system failure is defined in Section 3.1. An accurate measure of the response will be achieved by checking the tire condition at regular intervals along the test course in addition to any time the driver or data collector feels that a check is necessary. The test course will be 150 miles in length (five 30-mile laps), extending the course length used in the CDEC exercise. The hope is that this will result in fewer tires which travel the entire course length. In that event, the data is not considered to be truncated--important to the interpretation of statistical analysis and the estimation of factor influence.

A measure of power to the axle or driver's seat will be available, as it was for the WES analysis. TACOM will assume responsibility for the analysis of that information.

#### **3.2.2 Test Factors**

Test factors are those whose influence on the response is measured. The experimental design is in large measure defined by the manner in which they are included. The test factors considered here are tire technology, tire position, tire motion, tire pressure, driving team, and threat, which includes angle of obliquity. In this section, each will be discussed in turn.

The tire technology factor consists of six levels, corresponding to the standard and five prototypes. An influence on the response caused by this factor indicates that at least one of the technologies is performing differently than the others. Multiple comparison procedures will allow for the ranking of the prototypes in that likely event. The new prototypes under consideration were produced by Motor Wheel Corp., Lansing, MI; Patacell Corp., Long Island, NY; Trelleborg Corp., Sweden; Vorwerk Corp., Federal Republic of Germany; and Hutcheson Corp., France.

Tire position is included as a factor because of the different forces acting on steering tires as opposed to drive tires. Specifically, the drive tire experiences those forces associated with the forward motion of the vehicle. The steering tire experiences forces relating to vehicle control and drive forces during the 4-wheeled drive use of the vehicle. Tires mounted at both positions will be degraded and position performance will be compared. Additionally, four tests will be conducted with both the drive and steering tire degraded. This is necessary to meet the two-tire damage specifications in the NATO/FINABEL standard. This test of the two-tire damage case is mentioned in the final section of the report, and its position in the test sequence appears in italicized print in Appendix C.

Tire motion refers to whether the vehicle is moving or at rest. In the test, tires under load will be degraded under each condition. To safely accomplish degradation while the wheels are in motion, the BRL developed a test stand on which the vehicle can be mounted. Once mounted, the tires are rotated at 35 mph. The rationale for this factor is simply that some believe that the tires will respond differently to threat damage if in motion as compared to at rest. For instance, the centrifugal force in a moving tire may assist a chemical sealant in plugging any holes.

Tire pressure is believed to affect the damage inflicted by a round or fragment, low tire pressures making the tire more resistant to the damage. The test will reveal any differences between performance under high and low pressures. Also the performance under low pressure, important for certain terrains, may be evaluated. For example, tires with low pressures will normally perform better on soft, sandy, wet, marshy, or snow covered terrains, whereas tires with relatively high pressures will be more effective on "hard" surfaces such as concrete or macadam. TACOM has set high and low pressure to be 30psi and 22psi, respectively.

The factor, threat, consists of four levels of damage, two by shrapnel and two by 7.62mm rounds. The shrapnel damage is inflicted by a large and a small fragment, each with trajectories perpendicular to the side wall of the tire. More detailed information about the fragment simulation is given in Section 5.1. The ball ammunition damage is performed according to the NATO/FINABEL standard, calling for five rounds straight-on into the side wall and 2 rounds straight-on into the tread. A second

ammunition degradation is accomplished by firing five rounds into the side wall, with a 45° obliquity angle, and 2 rounds straight-on into the tread. The intent is to determine if the angle of attack influences tire degradation, and to compare both small and large fragment simulators with ball ammunition, as to their influence on tire performance.

The factor, driving team, was created to isolate the effects of different drivers on the response and to lessen the demands placed on individual drivers. With regard to tire failure definitions, varying driving skills and judgement could cause drivers to influence the measured response. Based on the speeds traveled in the CDEC exercise, the vehicle could have been required to stay on the course for six hours. Given the failure criteria, driver fatigue is to be avoided. The driver effect is not of interest in this investigation; it is merely a nuisance factor. Its influence will be reduced through use of the speed profile test discussed in Section 4.1, but it is still likely to be present to some degree. Therefore, the factor has to be measured so that its influence on the response can be distinguished from the effects of the more important factors. The tack taken was to create two driving teams, each having two drivers. The driving team factor will allow for the detection of differences between teams, but not the difference between drivers within teams. The latter difference will be reduced by partially randomizing the drivers within a given team. In this way, we avoid the situation where driver 1 always drives when testing prototype A and driver 2 always drives when testing prototype B. If the drivers were not partially randomized and a difference was observed between prototype A and prototype B, a natural concern would be that the observed difference was really between drivers and not prototypes. There would be no statistical way of determining the origin of the observed difference.

### 3.2.3 Nuisance Factors

Similar to the driving teams factor, nuisance factors are experimental conditions which will likely affect the response, but whose effect is not of interest. We will implement two methods for protecting the integrity of the design from these nuisance effects: control the influence by making the factor assume a constant value or relegate the influence to the experimental error through randomization of the factor. The latter approach is only appropriate when the amount of influence is expected to be small. The driving teams factor, for example, is really a nuisance factor but had to be incorporated in the design as a test factor because its influence was expected to be substantial. What follows is the discussion of five nuisance factors.

Terrain (primary, secondary, cross country) is going to influence tire performance by imposing different stresses on the tire. The influence is more appropriately measured by power to the axle and driver's seat than by the number of miles until failure. Its effect on that response is already addressed in detail in WES Technical

Report GL-87-21. The factor is important to the response adopted here, because the NATO/FINABEL standards define the tire's mission profile in terms of the three terrains. The procedure adopted here, consistent with the CDEC exercise, was to create a test course comprised of the three terrains in proportions consistent with the HMMWV mission profile. The order in which the terrain is accessed by the vehicle will be partially randomized.

Two HMMWVs will be used in the test. Though we have asked for vehicles of similar age and states of repair, the possibility still exists for each to handle differently, for example, different suspension systems expose the tires to different levels of stress. The vehicles are introduced to the design with driving team, i.e. each team will always drive the same vehicle. The impact this will have on the analysis is that their effects are confounded; a significant effect observed for driving team could be caused by a driving team difference or a vehicle difference. Since neither factor is of real interest except to partition the total variability of the data, this confounding is not perceived to be a problem.

High road temperature has been shown to be a significant contributor to the break-down of the tire. Consistent weather conditions are then important to the test outcome. In the CDEC exercise, one problem was that wet conditions, the presence of puddles, allowed the tire a chance to cool down. In this test, the intent is to control, as nearly as possible, the weather by choosing a hot and dry site for the worst possible case scenario.

Vehicle load contributes to the tire's stress. Again, for the worst possible case scenario, the vehicle will be loaded to the maximum 7900 pounds. The weight will be shifted toward the right side of the vehicle where the damaged tires will be positioned.

Driving speed is another contributor to tire stress. The adopted procedure is to instruct the drivers to travel quickly, while remaining in control. This too is consistent with the CDEC exercise. In the CDEC exercise, the average speed for primary roads was 35 miles per hour and approximately 18 miles per hour for both secondary and cross country.

### 3.3 Two-Stage Test Approach

Before settling on an approach to the testing we prioritized the objectives. Most important is the screening of STS systems to identify promising technologies for consideration in further study, that is, ranking the levels of the tire technology factor. Of secondary importance is the detailed evaluation of influencing factors. Due to the limited availability of prototypes and the large number of questions to be addressed, it is not possible to adequately handle all objectives simultaneously. We choose instead

to run the experiment in stages, utilizing information from the first stage to make the second stage more efficient, both in terms of resources and information gleaned.

In stage 1, the focus is on the influencing factors and not tire technology. In fact, only the standard HMMWV tire system will be tested. There are three reasons for first examining these factors. First, using the more plentiful HMMWV tire, more information can be acquired regarding each of the influencing factors; this leads to better decisions regarding the factor's effect. Second, some of the factors may prove to affect the response far less than originally anticipated; thus, they may be determined not essential in examining the new prototypes. Inclusion of factors in either situation, when testing the new prototypes, acts to divide the allocation of sparse samples unnecessarily, thereby lessening the sensitivity of the test. Third, the nature of such testing is to identify mistakes, initially. The stage 1 test allows an opportunity for resolving problems in the test procedure without wasting valuable resources, the new STS prototypes. More details of stage 1 are given in Section 4.2.

After the completion of stage 1, we will know more about the significance of the proposed experimental factors. At that time, decisions can be made as to their roles when comparing the STS prototypes. Because the factors to be used in stage 2 are not yet determined, we only outline the data acquisition and analysis in Section 4.3 as opposed to a detailed presentation. However, though details are not possible, the design will follow, in principle, the design of stage 1.

Prior to beginning stage 1 testing, a baseline test will be run to help profile the driving of each of the test participants. The purpose is to gather data to be used for statistically modeling driving performance under normal driving conditions. A normal driving speed will be determined for each of the three terrains. Those speeds will serve as the reference points, or baseline, against which the 50%-Rule is evaluated. In the section which follows, yielding to the chronology of experimentation, we describe the baseline test first.

#### **4. DATA ACQUISITION AND ANALYSIS, A SYNOPSIS**

The strategies given in Section 3 will be supported by the acquisition and analysis plan that follows. It has been expressed in an abbreviated format to facilitate its use as a general guide, with specific details relegated to the appendices. Each of the three tests (the two stages and the speed profile test) are described according to their purpose, the data to be acquired with the corresponding tire resources, and the intended analysis.

## **4.1 Speed Profile Test**

### **4.1.1 Purpose.**

- a) Establish a peak-performance baseline measurement for each driving team using the standard undamaged tire.
- b) Elicit driver/data collector evaluation of the standard tire.

### **4.1.2 Acquisition.**

- a) Operator instructions are to drive at speeds appropriate for the course so that they can maintain control. The Ft. Lewis results indicate that speeds of 37, 21, and 18 mph are attainable for primary, secondary, and cross country terrain under normal operating conditions. Each of two driving teams will travel 4 laps or 120 miles according to the driving schedule and team assignments given in Appendix B.
- b) Data will be gathered on time spent on each of the terrain types.
- c) Data will be gathered from drivers and data collectors by a questionnaire developed by the Probability and Statistics Branch of the BRL (included in Appendix A).
- d) Resource: 120 miles of wear on eight standard tires.

### **4.1.3 Analysis.**

- a) Using data collected according to 4.1.2 b), establish driving speed profiles for each team, profiling 3 terrain speeds as a function of miles driven. A statistical modeling procedure will be used to accomplish this task.
- b) Summarize questionnaire information for comparison with subsequent test results.

## **4.2 Stage 1**

### **4.2.1 Purpose.**

- a) Evaluate standard HMMWV tire after perforation.
- b) Determine which factors influence tire performance for the standard HMMWV tire.

- c) Decide which factors examined should be considered in testing of new tire technologies in Stage 2.
- d) Work out problems in testing, job assignment, and so forth, using the standard HMMWV tire.
- e) Gather driver/data collector evaluations of damaged standard tires.
- f) Gather tire changing evaluations.

#### 4.2.2 Acquisition.

- a) Data will be collected according to a  $1/2$  replicate of a  $4 \times 2^4$  factorial design (see Appendix B).
- b) Operator instructions are to try to maintain the speeds of Speed Profile Test, but to slow if necessary to keep vehicle under control. Travel 5 laps or 150 miles.
- c) Record time spent on each section of the course.
- d) Stop and examine tire condition after each lap and record tire condition.
- e) Collect data on miles to failure. (Tire failure occurs when tire auto-ignites, comes off the rim, or driver must reduce speed to 50% or below of appropriate baseline value).
- f) Collect questionnaire data from drivers/data collectors after 150 miles or tire failure. The questionnaire is given in Appendix B and is to be filled out separately by each member of the driving team.
- g) Comments on difficulty regarding mounting and demounting of the tires should be made on the appropriate form given in Appendix B.

- h) Resource: Use of 43 HMMWV tires:
- |          |   |
|----------|---|
| 32       | damaged in a $1/2$ replicate of a $4 \times 2^4$ design |
| 8        | damaged when examining 2-tires damaged effect           |
| <u>3</u> | left undamaged on vehicle                               |
| 43       |   |

#### 4.2.3 Analysis:

- a) Answer:
- i) Does performance after damage vary with tire pressure?
  - ii) Does performance after damage vary with tire position?
  - iii) Does performance after damage vary with tire motion?
  - iv) Does performance after damage vary with threat?
  - v) Does performance after damage vary with driving team?
  - vi) Do some factors affect the outcome differently according to varying levels of another factor? (1st order interaction.)
- b) Summarize questionnaire information.
- c) Decide which experiment factors should be examined further with new tire technologies.

#### 4.3 Stage 2 (Assumes no Factors eliminated after Stage 1.)

##### 4.3.1 Purpose:

- a) Purposes a, b, e, f of Stage 1 testing, but now for new tire technologies.
- b) Comparatively evaluate tires based on the objective and subjective information.

##### 4.3.2 Acquisition:

- a) Data collected according to a fractional replication of a  $5 \times 4 \times 2^4$  factorial design.
- b) Acquisition includes b and c from Speed Profile Test and b-g in Stage 1 testing.

c) Details pertaining to analysis cannot be finalized until the completion of evaluation testing.

d) Resource: Use of 30 tires of each of 5 types (150 total)

#### 4.3.3 Analysis:

a) All factors from 4.2.3.

b) Answers - which tire performs best?

### 5. SPECIAL CONSIDERATIONS

#### 5.1 Characterization of the Fragment Threat

The purpose of fragment damage simulation is to determine the influence of fragment-induced damage on run-flat tire performance and to allow for comparisons between fragment-induced damage and damage caused by 7.62 mm ball ammunition. For this test, a prime consideration is the nature of the threat, as characterized by mass, velocity, shape and expected number of hits. We fixed fragment parameters to correspond with two known threats, a 152mm and a 122mm round. The Army Materiel Systems Analysis Activity (AMSAA) suggested the two threats which should be represented. Once these parameters were determined, a fragment design was developed which caused the simulators to tumble in flight, causing representative tearing on impact.

For each threat, we proceeded as follows: Velocity and mass are functions of shell orientation and the distance to the tire at detonation. AMSAA accounted for shell orientation in an AMSAA model. BRL's interpretation of a TACOM requirement called for setting the distance equal to that causing 50% M-kill. In an attempt to representatively simulate damage, a special fragment simulator was made which had small length over diameter ratio. The result was a 3 gram and 10 gram fragment simulator to be fired at 2600 fps and 3000 fps, respectively, with the expected number of hits set according to the presented area of the tire and the size of the fragment. For the distance setting chosen, the 5 side wall/ 2 tread approach suggested in the NATO/FINABEL standard is close to what we might expect.

The initial simulators' performance was deemed unsatisfactory by an AMSAA tire analyst, who based the judgement on many test shots run at the BRL and the Meppen Trials. His basis for comparison was actual fragment damage. The complaint was that the shots were not cutting enough, and were too small. BRL changed the fragment design to right circular cylinders.

In order to improve the "tearing" characteristics of the fragments, we experimented with a design having high length-to-diameter (L/D) ratio. It was discovered that grooving the base end of the simulator would cause it to tumble. Resulting perforations are thus elongated and similar to perforations from actual fragments (see Figure 5.1).. After examining the results, the AMSAA analyst agreed to the use of the design during the test. It is worthy of note that the time from perforation to tire system flat was nominally the same for both types of fragments.

## **5.2 Development of the BRL Test Stand**

### **5.2.1 Purpose**

In previous tests, all tire system perforations had been accomplished statically. A concern was expressed by the Vulnerability/Lethality Division analyst of BRL that multiple impacts on rolling tire systems may have an appreciably different effect than impacts on static tire systems. It was decided by BRL to design and construct a test stand that would allow all of the vehicle's wheels to rotate at speeds up to 35mph at fragment impact in order to address this concern.

### **5.2.2 Performance of STS after Perforation**

Response to single perforations of a single rolling tire system caused some sideways drifting of the vehicle. Single perforations of two tire systems on one vehicle caused a dramatic sideways drift of the vehicle. Both reactions could have caused tire systems or vehicle damage not observable during static tests. It is highly probable that reactions of this nature will require skill on the part of the driver in order to maintain control. In addition, damage to the vehicle was sustained during test firings which was unexpected, to wit: during one firing, the rotating tire caused the fragment simulator to deflect into the fuel tank, causing a probable Mobility-kill; during a second firing, a shock was severely damaged, which probably would have caused a mobility kill sooner than tire system failure; during a third firing, two laterally-opposed rear tires were perforated. The current NATO/FINABEL does not account for this type of event.

## **6. THE TEST IN REVIEW**

The program for which this test was constructed has as its goal the fielding of more survivable tires on the battlefield. In the development phases, it is necessary to examine carefully all the known technological options, eliminating some as impractical or inefficient and endorsing others as sufficiently promising to continue to the next development phase. It is to this development task, screening out the impractical or inefficient, that we structured the test described in this paper. In doing so, we had to assess the influence of experimental factors representing battlefield conditions. This,

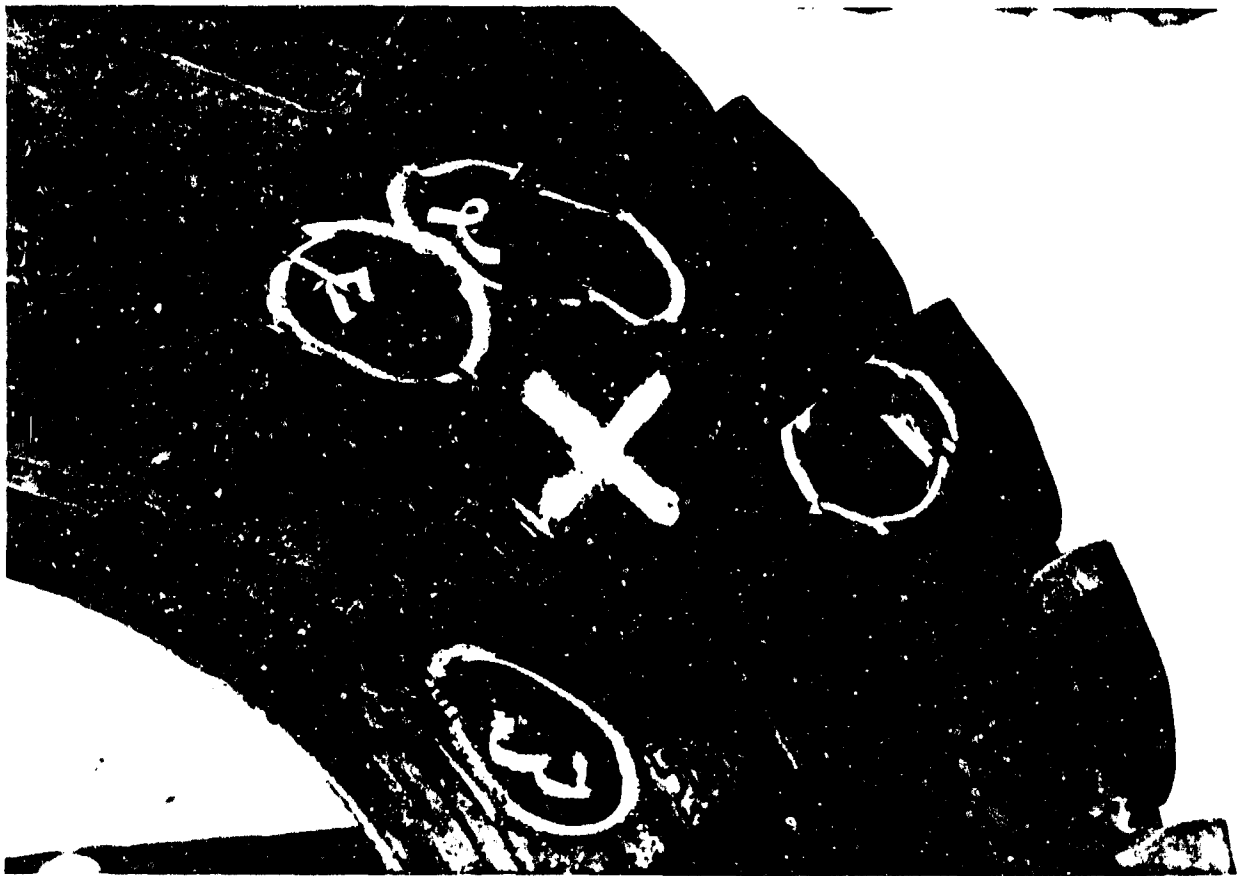


Figure 5.1. Elongated perforations caused by high L/D ratio fragment simulators.

in turn, necessitated a practicable means for simulating fragment damage and for shooting tires which were in motion and under load. The former required simulation modeling to establish a representative fragment threat and testing of the fragments to insure their suitability. The latter required the development of new equipment, the BRL test stand, specifically designed to safely simulate damage inflicted on tires when moving on the battlefield. The complexity of the issues and the scarcity of tire resources suggested that the technical testing program be handled in stages. Keeping the experimental bite manageable will allow for clear answers to the questions that have been posed.

There is no perfect test; therefore, we are well-advised to recognize its strengths and weaknesses. We address the primary advantages and disadvantages of the test plan, interpreted in terms of the stated military and experimental objectives. Beginning with the military objectives, all of the variables considered important by TACOM or the NATO/FINABEL Standards are included in the test plan in a manner suitable to TACOM. Sometimes this required compromise, such as in the use of terrain. Terrain is considered only through its inclusion in the test course in proportions consistent with the HMMWV mission profile. For some other variables the military interests are clarified in the test plan. For example, normal operating speeds in the failure definition are more sensibly tied to the normal performance of individual driving teams. Efforts to handle the fragment threat resulted in a reasonable fragment simulation procedure. Battlefield tire motion and load can now be simulated using the BRL test stand.

With regard to experimental objectives, the selection of STS prototypes for further research and development follows directly from analysis of the second testing stage. Further, the stage 1 plan imposes an analyzable design structure on a complex problem providing for the testing of all important hypotheses. In addition, running the experiment in stages has the emphasis and resource advantages mentioned in Section 3.3. However, the test plan has several weaknesses. By examining the standard tire only in stage 1, comparisons between it and other STS prototypes are hindered. Experimental error is an issue since complete randomization is not possible and since some pooling of low-order interactions into the error term may be necessary. Choice of an error term for the imbedded test of the two-tire effect is far from straightforward, particularly since four of the eight observations must be used in the analysis twice. Finally, we had to take some liberties in the combination of variables to form factors so that a design would be possible with the available samples.

## REFERENCES

1. Drelling, J., Pietzyk, S., Schrag, H. [1987], "Survivable Tire Test," Technical Report CDEC-TR-87-014, Combat Developments Experimentation Center.
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3. Cochran, W., Cox, G., "Experimental Design," John Wiley and Sons, New York [1957].
4. Kempthorn, O., "The Design and Analysis of Experiments," John Wiley and Sons, New York [1952].
5. NATO/FINABEL Standard [1984].

## APPENDIX A - SPEED TRIAL INFORMATION

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## APPENDIX A - SPEED TRIAL INFORMATION

The primary purpose for this test is to establish baseline performance levels for each driving team. These levels will be established using regression or time series analysis. They will be used in establishing speed-induced failure criteria to be used in evaluation testing.

### Tire & Vehicle Identification & Initial State

- 1) Clearly mark the 2 HMMWV's as vehicles 1 and 2.
- 2) Paint both side walls of each of the 43 tires white.
- 3) Code tires 1 through 43 roughly according to their order of arrival if possible
- 4) Initially mount the tires (by number) as indicated below and inflate all to high manufacturer recommended pressure. The driver side is considered the left.

Vehicle 1	RF-6	RR-22	LF-40	LR-36
Vehicle 2	RF-37	RR-24	LF-10	LR-9

- 5) Load each vehicle to 7900 lbs insuring that the right side of the vehicle is the heavier side.

## DRIVING SCHEDULE & TEAM ASSIGNMENTS

Driving for this test program will be accomplished with two teams. Each driver will be assigned a **Team #** and a **Driver #**. Once assigned, the driver will retain these two numbers for all testing described in Part 1 - Part 3.

Drivers will be asked to perform two tasks. They will either be driving the vehicle or performing as data collector. The data collector has the responsibility to record time spent on each section of course and note any tire or mechanical problems experienced.

Test Sequence #	Team	Vehicle	Lap	Tire Pressure	Driver #	Data Collector #
A1	1	1	1	High	1	2
A2	1	1	2	High	2	1
A3	1	1	3	Low	1	2
A4	1	1	4	Low	2	1
A5	2	2	1	High	1	2
A6	2	2	2	High	2	1
A7	2	2	3	Low	1	2
A8	2	2	4	Low	2	1

Each driver will record his rating on the tire evaluation sheet after lap 2, for laps 1 and 2, and after lap 4, for laps 3 and 4.

## TIRE EVALUATION

Please read the instructions on the reverse side of this form before completing. Indicate Test Sequence #, Team #, and Driver #. Circle one response for each performance category and include any comments in the space provided.

Test Sequence # \_\_\_\_\_

Team # \_\_\_\_\_

Driver # \_\_\_\_\_

\_\_\_\_\_  
Traction:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

\_\_\_\_\_  
Stability:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

\_\_\_\_\_  
Vibration & Shimmy:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

\_\_\_\_\_  
Steering:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

\_\_\_\_\_  
Control:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:

## INSTRUCTIONS

Following are some instructions pertaining to tire system rating. When rating the tire try to focus attention on only the category in question. This, we realize, is not an easy task since there necessarily is overlap among them. For example avoid down weighting the tire score on traction because of an annoyingly bumpy ride. Some examples of specific problems which could be encountered in each category are given below. Please read carefully the description associated with each of the possible ratings.

### Categories

Traction (sliding, spinning, fish tailing, hydroplaning, reduced speed)

Stability (vehicle swaying, tires stiff)

Vibration & Shimmy

Steering (pulling to one side, wandering)

Control (poor handling, rough ride, bouncing)

### Ratings

- |               |   |  |
|---------------|---|--|
| Very Good     | - | no problems with respect to this category and performance is very good.                |
| Good          | - | no identifiable problems, but performance did not warrant a "Very Good" rating.        |
| Above Average | - | 1 or 2 identifiable problems, but performance was still "Fairly Good".                 |
| Below Average | - | 1 or 2 identifiable problems resulting in performance below the "Fairly Good" level.   |
| Poor          | - | more than 2 identifiable problems, but performance still marginal.                     |
| Very Poor     | - | more than 2 identifiable problems resulting in performance below the "Marginal" level. |

**NOTE:** All ratings made for prototype tires are to be "relative to the standard HMMWV tire performance".

APPENDIX B -  $4 \times 2^4$  FACTORIAL DESIGN: 1/2 REPLICATE

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## APPENDIX B - $4 \times 2^4$ FACTORIAL DESIGN: 1/2 REPLICATE

Definition; A  $4 \times 2^4$  factorial design tests each possible treatment combination of 1 factor with 4 possible levels and 4 factors with 2 possible levels. A 1/2 replicate of such a design selects 1/2 of the  $4 \times 2^4$  possible combinations (32 observations).

Design Factors: Factors varied in the design:

- |             |   |          |
|-------------|---|----------|
| a) pressure | - manufacturer's high and low pressure              | 2 levels |
| b) motion   | - dynamic (35 mph) or static                        | 2 levels |
| c) position | - drive only or steering                            | 2 levels |
| d) team     | - driving teams                                     | 2 levels |
| e) threat   | - 7.62 mm rounds (2 at 0°, 5 at 90°)                | 4 levels |
|             | - 7.62 mm rounds (2 at 0°, 5 at 45°)                |          |
|             | - Small fragment simulator (SF) (2 at 0°, 5 at 90°) |          |
|             | - Large fragment simulator (LF) (2 at 0°, 5 at 90°) |          |

Fractional factorial designs are common tools in industrial experiments. Their great advantage is that they provide an efficient means for examining the influence of many factors in one design. The advantage comes at a price depending on the particular design chosen; a fractional factorial design creates an indeterminacy among certain factors, that is, one cannot tell which of the linked factors truly influenced the response variable.

The 1/2 replicate of the  $4 \times 2^4$  design in the Evaluation guarantees that principal factors and 2-way interactions can all be differentiated clearly from one another. Indeterminacy between them and higher order interactions does exist. The analyst assumes that the higher order interaction is not present and that the principal factor or 2-way interaction is important. This is loosely analogous to approximating a curve with a second order Taylor series approximation.

TEST SCHEDULE							
Testing Sequence	Threat	Team	1st Driver	Vehicle	Tire Pressure	Tire Position	Tire Motion
1	SF	2	2	2	low	drive	dynamic
2	SF	1	1	1	low	steering	dynamic
3	7.62/45°	2	1	2	high	steering	static
4	SF	1	2	1	high	steering	static
5	LF	2	2	2	high	drive	dynamic
6	LF	1	2	1	low	steering	static
7	LF	2	1	2	high	steering	static
8	7.62/90°	1	2	1	high	steering	static
9	LF	2	1	2	low	steering	dynamic
10	7.62/90°	1	1	1	low	2-tire	dynamic
11	7.62/45°	2	2	2	high	drive	dynamic
12	7.62/90°	1	1	1	low	steering	dynamic
13	7.62/90°	2	2	2	low	drive	dynamic
14	7.62/90°	1	2	1	low	drive	static
15	SF	2	1	2	high	2-tire	dynamic
16	SF	1	2	1	low	drive	static
17	7.62/45°	2	2	2	low	steering	dynamic
18	LF	1	1	1	low	drive	dynamic
19	SF	2	1	2	high	drive	static
20	SF	1	2	1	low	2-tire	dynamic

TEST SCHEDULE							
Testing Sequence	Threat	Team	1st Driver	Vehicle	Tire Pressure	Tire Position	Tire Motion
21	SF	2	2	2	high	steering	dynamic
22	7.62/45°	1	2	1	high	drive	static
23	7.62/90°	2	2	2	high	drive	static
24	7.62/45°	1	1	1	low	drive	dynamic
25	7.62/90°	2	1	2	low	steering	static
26	LF	1	1	1	high	drive	static
27	SF	2	1	2	low	steering	static
28	7.62/45°	1	2	1	high	steering	dynamic
29	7.62/90°	2	1	2	high	2-tire	dynamic
30	7.62/90°	1	2	1	high	drive	dynamic
31	7.62/45°	2	1	2	low	drive	static
32	SF	1	1	1	high	drive	dynamic
33	LF	2	2	2	low	drive	static
34	7.62/45°	1	1	1	low	steering	static
35	7.62/90°	2	2	2	high	steering	dynamic
36	LF	1	1	1	high	steering	dynamic

\* Driver and data collector will change roles after each lap.

## TIRE EVALUATION

Please read the instructions on the reverse side of this form before completing. Indicate Test Sequence #, Team #, and Driver #. Circle one response for each performance category and include any comments in the space provided.

Test Sequence # \_\_\_\_\_

Team # \_\_\_\_\_

Driver # \_\_\_\_\_

\_\_\_\_\_  
Traction:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

\_\_\_\_\_  
Stability:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

\_\_\_\_\_  
Vibration & Shimmy:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

\_\_\_\_\_  
Steering:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

\_\_\_\_\_  
Control:      Very Good      Good      Above Average      Below Average      Poor      Very Poor

Comments:  
\_\_\_\_\_

## INSTRUCTIONS

Following are some instructions pertaining to tire system rating. When rating the tire try to focus attention on only the category in question. This, we realize, is not an easy task since there necessarily is overlap among them. For example avoid down weighting the tire score on traction because of an annoyingly bumpy ride. Some examples of specific problems which could be encountered in each category are given below. Please read carefully the description associated with each of the possible ratings.

### Categories

Traction (sliding, spinning, fish tailing, hydroplaning, reduced speed)

Stability (vehicle swaying, tires stiff)

Vibration & Shimmy

Steering (pulling to one side, wandering)

Control (poor handling, rough ride, bouncing)

### Ratings

- |               |   |  |
|---------------|---|--|
| Very Good     | - | no problems with respect to this category and performance is very good.                |
| Good          | - | no identifiable problems, but performance did not warrant a "Very Good" rating.        |
| Above Average | - | 1 or 2 identifiable problems, but performance was still "Fairly Good".                 |
| Below Average | - | 1 or 2 identifiable problems resulting in performance below the "Fairly Good" level.   |
| Poor          | - | more than 2 identifiable problems, but performance still marginal.                     |
| Very Poor     | - | more than 2 identifiable problems resulting in performance below the "Marginal" level. |

**NOTE:** All ratings made for prototype tires are to be "relative to the standard HMMWV tire performance".

## TIRE CHANGING EVALUATION

- 1) Record Test Sequence # \_\_\_\_\_
- 2) Name of tire changer \_\_\_\_\_
- 3) Comment on difficulties with mounting or demounting tires.

Mounting:

Demounting:

## APPENDIX C - DETAILED TEST SCHEDULE

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TABLE C1. DETAILED TEST SCHEDULE

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	2	2	37	RF	low		none	1
			24	RR	low	dynamic	SF	
			10	LF	low		none	
			9	LR	low		none	

Notes: Replace damaged tire with tire 14

1	1	1	6	RF	low	dynamic	SF	2
			22	RR	low		none	
			40	LF	low		none	
			36	LR	low		none	

Notes: Replace damaged tire with tire 12

2	1	2	37	RF	high	static	7.62/45°	3
			14	RR	high		none	
			10	LF	high		none	
			9	LR	high		none	

Notes: Replace damaged tire with tire 35

1	2	1	12	RF	high	static	SF	4
			22	RR	high		none	
			40	LF	high		none	
			36	LR	high		none	

Notes: Replace damaged tire with tire 18

TABLE C1. DETAILED TEST SCHEDULE (Continued)

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	2	2	35	RF	high		none	5
			14	RR	high	dynamic	LF	
			10	LF	high		none	
			9	LR	high		none	

Notes: Replace damaged tire with tire 4

1	2	1	18	RF	low	static	LF	6
			22	RR	low		none	
			40	LF	low		none	
			36	LR	low		none	

Notes: Replace damaged tire with tire 23

2	1	2	35	RF	high	static	LF	7
			4	RR	high		none	
			10	LF	high		none	
			9	LR	high		none	

Notes: Replace damaged tire with tire 20

1	2	1	23	RF	high	static	7.62/90°	8
			22	RR	high		none	
			40	LF	high		none	
			36	LR	high		none	

Notes: Replace damaged tire with tire 38

TABLE C1. DETAILED TEST SCHEDULE (Continued)

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	1	2	20	RF	low	dynamic	LF	9
			4	RR	low		none	
			10	LF	low		none	
			9	LR	low		none	

Notes: Rotate LR(9) to RF and mount tire 41 on LR at conclusion of trial

1	1	1	38	RF	low	dynamic	7.62/90°	10
			22	RR	low	dynamic	7.62/90°	
			40	LF	low		none	
			36	LR	low		none	

Notes: Rotate LR(36) to RR and mount tire 1 on LR and tire 11 on RF at conclusion of trial

2	2	2	9	RF	high		none	11
			4	RR	high	dynamic	7.62/45°	
			10	LF	high		none	
			41	LR	high		none	

Notes: Rotate LF(10) to RR and mount tire 7 on LF at conclusion of trial

1	1	1	11	RF	low	dynamic	7.62/90°	12
			36	RR	low		none	
			40	LF	low		none	
			1	LR	low		none	

Notes: Rotate LF(40) to RF and mount tire 13 on LF at conclusion of trial

TABLE C1. DETAILED TEST SCHEDULE (Continued)

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	2	2	9	RF	low		none	13
			10	RR	low	dynamic	7.62/90°	
			7	LF	low		none	
			41	LR	low		none	

Notes: Replace damaged tire with tire 16

1	2	1	40	RF	low		none	14
			36	RR	low	static	7.62/90°	
			13	LF	low		none	
			1	LR	low		none	

Notes: Replace damaged tire with tire 29

2	1	2	9	RF	high	dynamic	SF	15
			16	RR	high	dynamic	SF	
			7	LF	high		none	
			41	LR	high		none	

Notes: Rotate LR(41) to RF and mount tire 31 on LR and tire 39 on RR at conclusion of trial

1	2	1	40	RF	low		none	16
			29	RR	low	static	SF	
			13	LF	low		none	
			1	LR	low		none	

Notes: Replace damaged tire with tire 17

TABLE C1. DETAILED TEST SCHEDULE (Continued)

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	2	2	41	RF	low	dynamic	7.62/45°	17
			39	RR	low		none	
			7	LF	low		none	
			31	LR	low		none	

Notes: Replace damaged tire with tire 19

1	1	1	40	RF	low		none	18
			17	RR	low	dynamic	LF	
			13	LF	low		none	
			1	LR	low		none	

Notes: Replace damaged tire with tire 33

2	1	2	19	RF	high		none	19
			39	RR	high	static	SF	
			7	LF	high		none	
			31	LR	high		none	

Notes: Replace damaged tire with tire 43

1	2	1	40	RF	low	dynamic	SF	20
			33	RR	low	dynamic	SF	
			13	LF	low		none	
			1	LR	low		none	

Notes: Rotate LF(13) to RR and mount tire 42 on RF and mount tire 21 on LF  
at conclusion of trial

TABLE C1. DETAILED TEST SCHEDULE (Continued)

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	2	2	19	RF	high	dynamic	SF	21
			43	RR	high		none	
			7	LF	high		none	
			31	LR	high		none	

Notes: Rotate LF(7) to RF and mount tire 2 on LF at conclusion of trial

1	2	1	42	RF	high		none	22
			13	RR	high	static	7.62/45°	
			21	LF	high		none	
			1	LR	high		none	

Notes: Rotate LR(1) to RR and mount tire 25 on LR at conclusion of trial

2	2	2	7	RF	high		none	23
			43	RR	high	static	7.62/90°	
			2	LF	high		none	
			31	LR	high		none	

Notes: Rotate LR(31) to RR and mount tire 8 on LR at conclusion of trial

1	1	1	42	RF	low		none	24
			1	RR	low	dynamic	7.62/45°	
			21	LF	low		none	
			25	LR	low		none	

Notes: Replace damaged tire with tire 28

TABLE C1. DETAILED TEST SCHEDULE (Continued)

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	1	2	7	RF	low	static	7.62/90°	25
			31	RR	low		none	
			2	LF	low		none	
			8	LR	low		none	

Notes: Replace damaged tire with tire 3

1	1	1	42	RF	high		none	26
			28	RR	high	static	LF	
			21	LF	high		none	
			25	LR	high		none	

Notes: Replace damaged tire with tire 5

2	1	2	3	RF	low	static	SF	27
			31	RR	low		none	
			2	LF	low		none	
			8	LR	low		none	

Notes: Replace damaged tire with tire 30

1	2	1	42	RF	high	dynamic	7.62/45°	28
			5	RR	high		none	
			21	LF	high		none	
			25	LR	high		none	

Notes: Rotate LR(25) to RF and mount tire 32 on LR at conclusion of trial

TABLE C1. DETAILED TEST SCHEDULE (Continued)

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	1	2	30	RF	high	dynamic	7.62/90°	29
			31	RR	high	dynamic	7.62/90°	
			2	LF	high		none	
			8	LR	high		none	

Notes: Rotate LR(8) to RF and mount tire 34 on LR and tire 27 on RR  
at conclusion of trial

1	2	1	25	RF	high		none	30
			5	RR	high	dynamic	7.62/90°	
			21	LF	high		none	
			32	LR	high		none	

Notes: Rotate LF(21) to RR and mount tire 26 on LF at the conclusion of trial

2	1	2	8	RF	low		none	31
			27	RR	low	static	7.62/45°	
			2	LF	low		none	
			34	LR	low		none	

Notes: Rotate LF(2) to RR and mount tire 15 on LF at the conclusion of trial

1	1	1	25	RF	high		none	32
			21	RR	high	dynamic	SF	
			26	LF	high		none	
			32	LR	high		none	

Notes:

TABLE C1. DETAILED TEST SCHEDULE (Continued)

Team	First Driver	Vehicle	Tire	Position	Pressure	Motion	Threat	Trial #
2	2	2	8	RF	low		none	33
			2	RR	low	static	LF	
			15	LF	low		none	
			34	LR	low		none	

Notes: None

1	1	1	25	RF	low	static	7.62/45°	34
			8	RR	low		none	
			26	LF	low		none	
			32	LR	low		none	

Notes: Before trial, borrow RF(8) from vehicle 2 to place on RR

2	2	2	8	RF	high	dynamic	7.62/90°	35
			26	RR	high		none	
			15	LF	high		none	
			34	LR	high		none	

Notes: Return before trial RR(8) from vehicle 1 to RF. Borrow from vehicle 1 LF(26)

1	1	1	32	RF	high	dynamic	LF	36
			26	RR	high		none	
			15	LF	high		none	
			34	LR	high		none	

Notes: Before trial, rotate LR(32) to RF and then place 3 remaining tires of vehicle 2 on vehicle 1

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## APPENDIX D - TEST REQUIREMENTS

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## APPENDIX D - TEST REQUIREMENTS

- A. Site suitable for firing shrapnel simulators (See Safety Standard Operating Procedure, Appendix - D).
- B. A thirty mile vehicle course which is segmented into three segments in accordance with the mission profile.
- C. Two HMMWVs in good repair.
- D. Four drivers/data collectors.
- E. Timing devices.
- F. Data recorders (acceleration).
- G. Firing device.
- H. Gun crew.
- I. Shrapnel simulators and propellant.
- J. Thirty tires of each prototype manufacture.
- K. Forty-three HMMWV run-flat tires.

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## **APPENDIX E - TEST STAND SPECIFICATIONS**

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## APPENDIX E - TEST STAND SPECIFICATIONS

The primary purpose of the test stand is to allow the tire systems to be degraded safely while rotating. There is concern that rotating tire systems will degrade in a different manner from tire systems degraded statically.

This test stand was designed and constructed by the BRL. It consists of a one inch plate of mild steel supported by two five inch I-beams. Four 24"x24" holes were cut into the plate to accommodate pillow block bearings and rollers (Figures E1, E2, and E3).

### Stand Specifications

Length	- 16'
Width	- 12'
Height	- 6"
Rollers	- 4 1/2" outside diameter - 24" in length
Pillow Block Bearings	- 1 1/2" inside diameter
Maximum Weight Capacity	- 40,000lbs (10,000lbs per roller set)

The vehicle can be driven onto the stand; after it is positioned the vehicle is secured against forward, backward, and lateral movement with locking chain tie downs (Figures E4, E5, and E6), necessary because of the tendency of the vehicle to slow dramatically when tire systems are degraded. Once the vehicle is secured, a lanyard is attached to the throttle to permit engine shut down. Upon completion of the firings, the vehicle is removed from the stand by towing and turned over to the test course driver for the completion of the evaluation.

In order to degrade the tire systems in a uniform manner, the BRL designed and constructed two firing platforms each with provision for mounting up to five weapons (Figure E7). The weapons chosen for degrading the systems were .308 calibre bolt-action rifles, as those rifles are capable of firing both the standard NATO cartridge and the fragment simulators. The rifles are fired simultaneously by attaching lanyards with a pulley system to each trigger and connecting them to a single draw string.

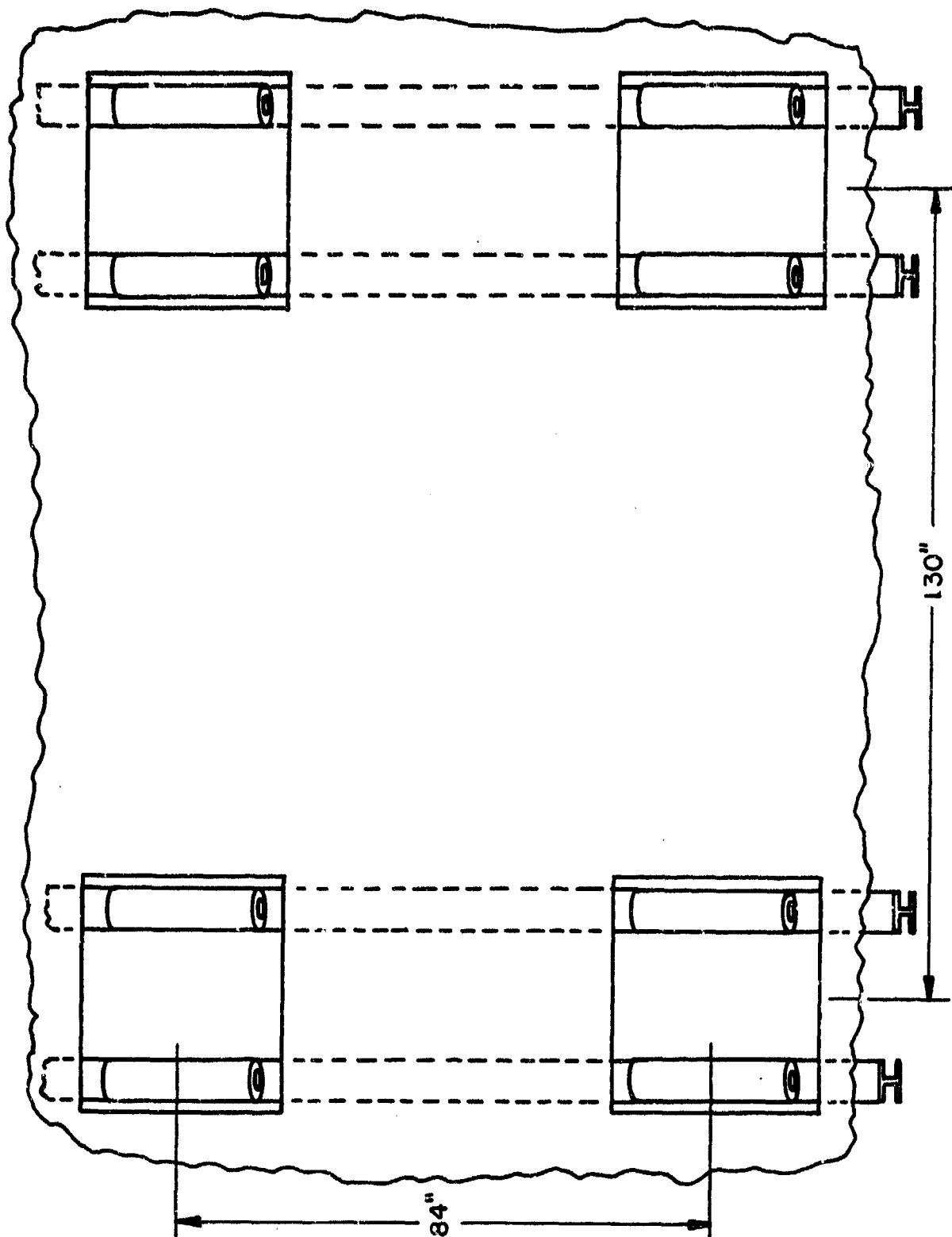


Figure E1. Top view of test stand.

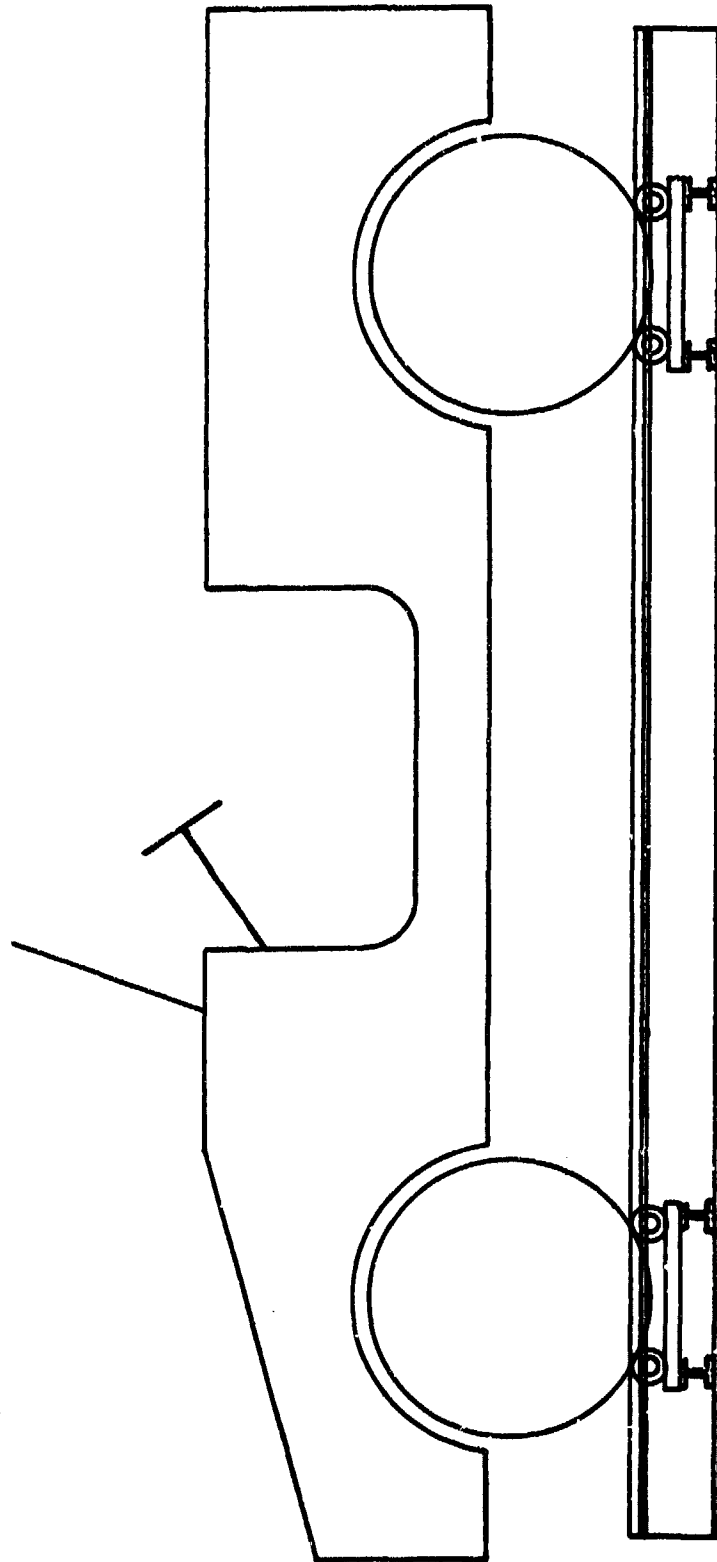


Figure E2. Side view of test stand.

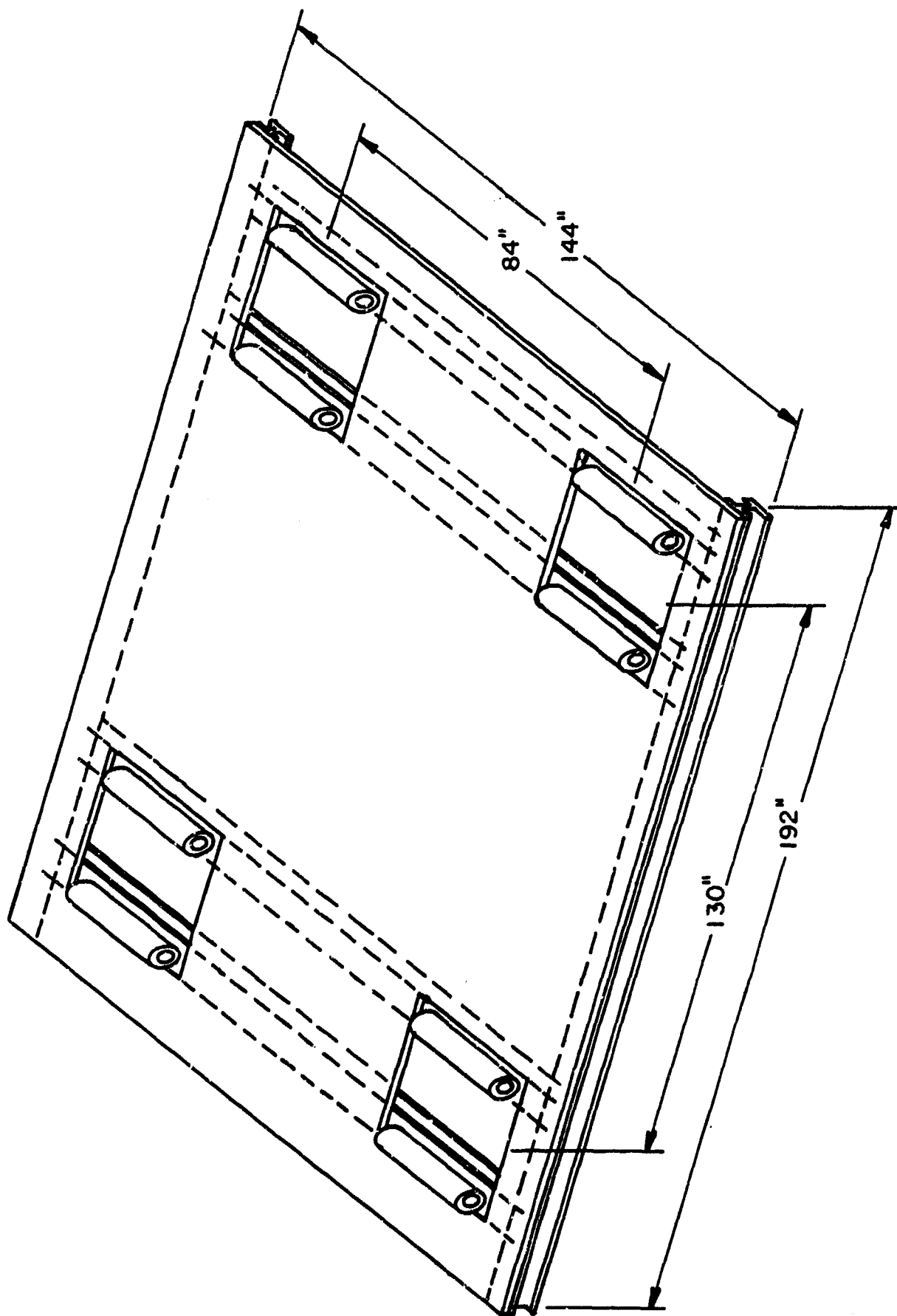


Figure E3. Test stand dimensions.



Figure E4. Front view of vehicle on test stand.

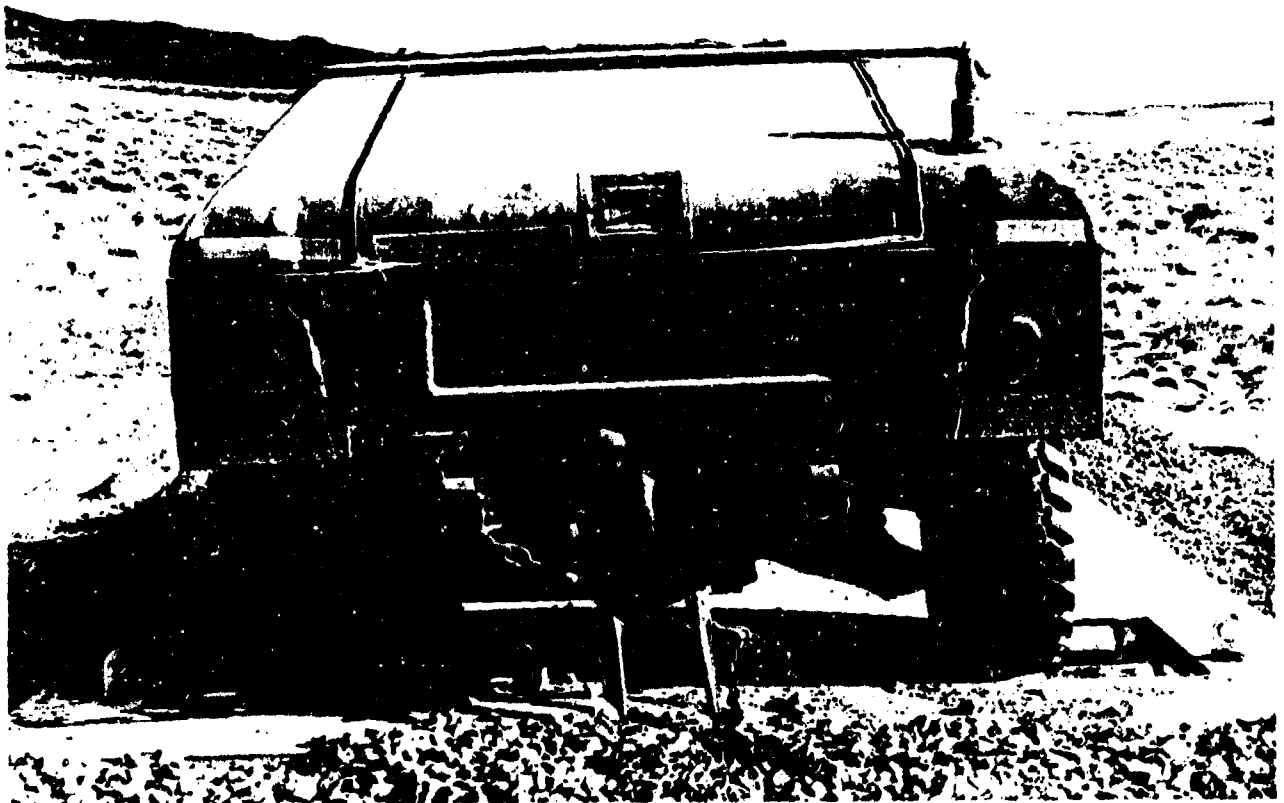


Figure E5. Rear view of vehicle on test stand.

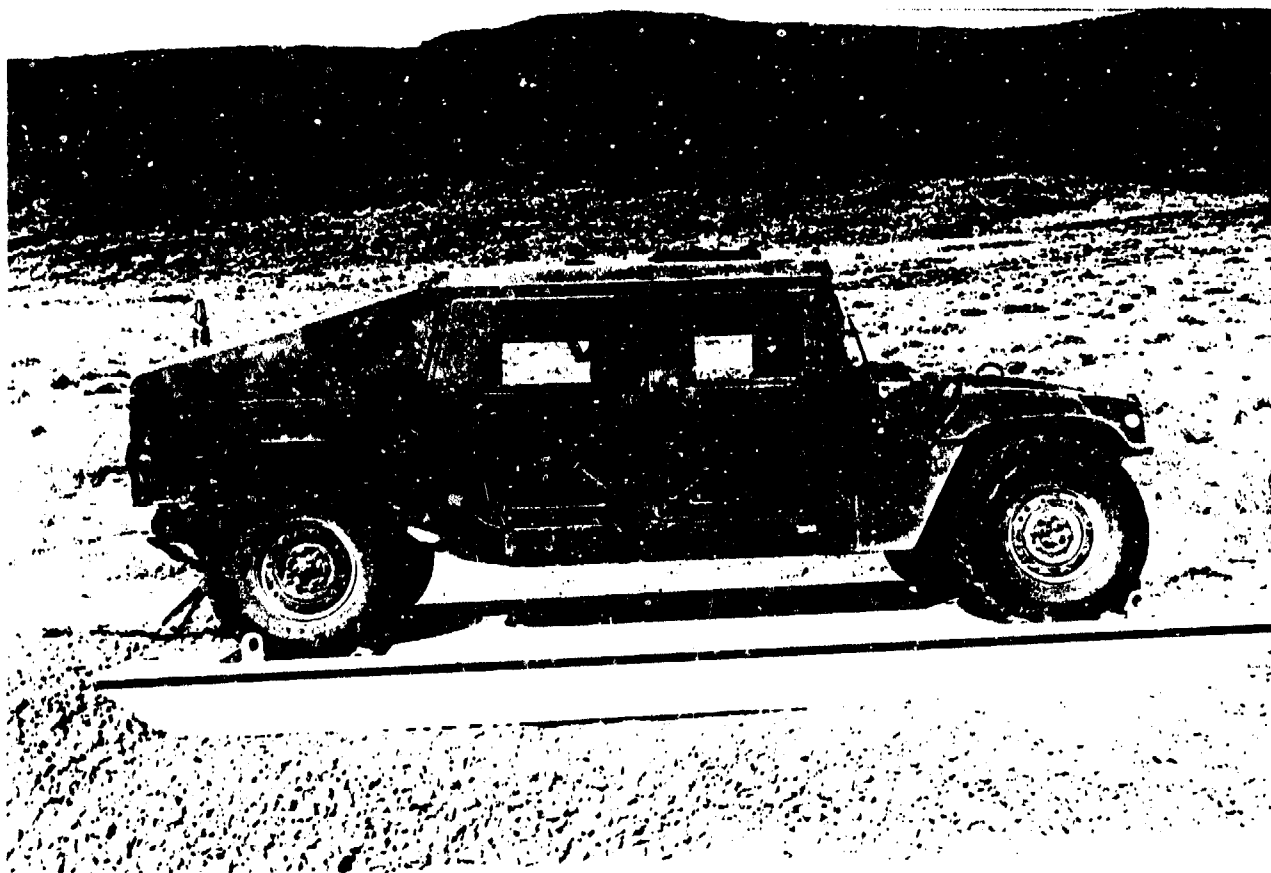


Figure E6. Side view of vehicle on test stand.

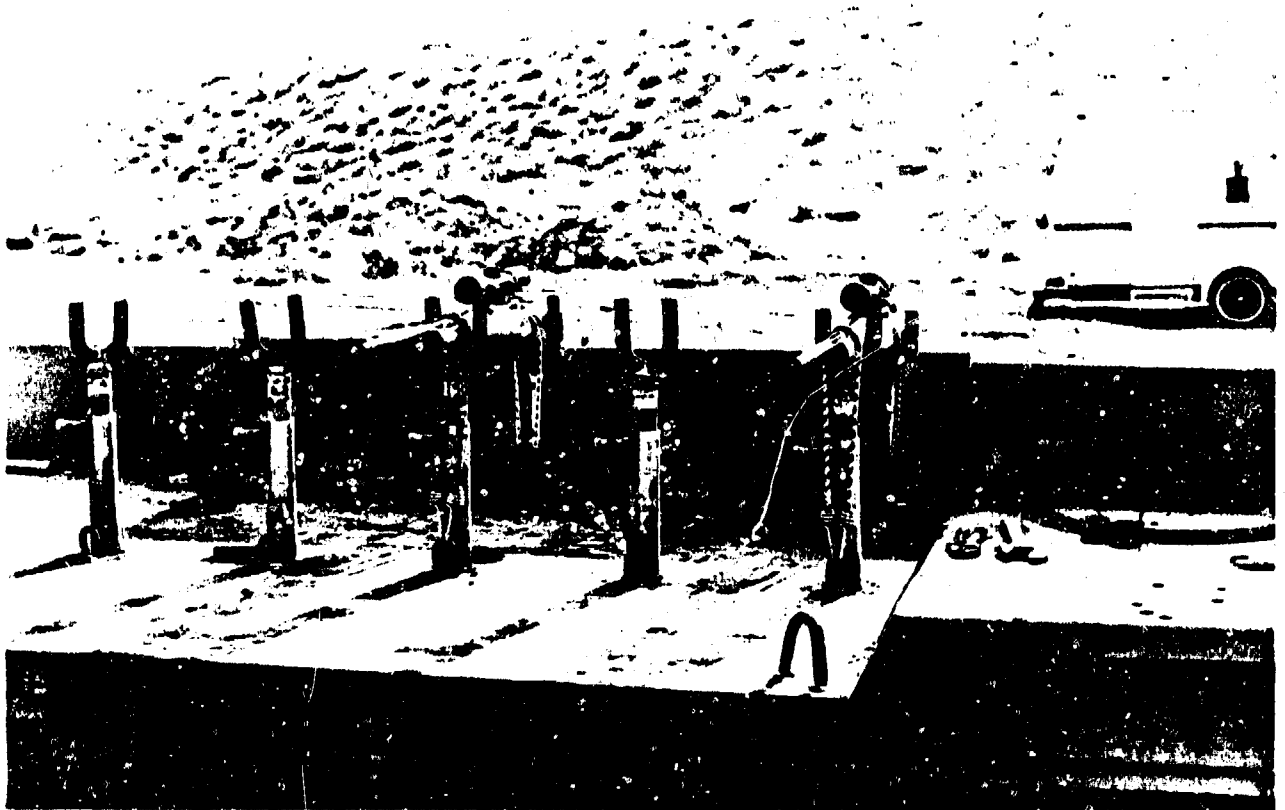


Figure E7. Weapons platform with two .308 caliber weapons mounted.

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